Endotracheal resuscitation of neonates using a rebreathing bag

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Abstract

Thirty asphyxiated neonates were resuscitated endotracheally with an anaesthetic rebreathing bag. The system was not limited either by pressure or by volume and chest movement was used as the criterion for adequate inflation. Inflation pressure and flow were recorded during resuscitation, and flow was integrated to obtain volume. Median mean pressure over the first 10 inflations was 40 cm H_2O and this dropped during later resuscitation to 29 cm H_2O. The volume delivered did not change significantly, so volume divided by pressure increased from a median of 0·18 to 0·35 ml/kg/cm H_2O. Fourteen infants formed part of their functional residual capacity with artificial ventilation and five with spontaneous breaths. Eleven infants showed no evidence of functional residual capacity formation. In the 22 preterm infants there was a strong association between absence of functional residual capacity formation and later hyaline membrane disease that required ventilation.

We suggest that pressures of more than than 30 cm H_2O may be helpful during initial resuscitation and that there should be further study of devices using positive end expiratory pressure for resuscitation of preterm infants.

Despite recent advances in management, birth asphyxia remains a major cause of mortality and morbidity.[1] Though there is much interest in it, comparatively little attention has been paid to the methods of resuscitation and their mechanisms. Pioneering studies by Ditchburn *et al*,[2] Hey and Kelly,[3] and Hull[4] used a volume limited system and were unable to measure the volumes of individual inflations. Hull stated that 30 cm H_2O was a suitable pressure at which to set the 'blow off' valve during resuscitation, but recognised that this would not be adequate for some infants.[4]

Boon *et al* studied resuscitation using a T piece and finger occlusion technique.[5] Though they limited pressure to 30 cm H_2O, their work did yield important information about the response to resuscitation[5] and formation of the functional residual capacity.[6]

All such previous work, however, has limited either volume or pressure, which may have significantly affected the results. In addition, improvements in obstetric care and maternal anaesthesia, and greater use of neonatal mask resuscitation, have led to a reduction of intubation rates for resuscitation.[7] The characteristics of babies requiring intubation have, therefore, changed during recent years and so also have their requirements for effective resuscitation. Finally, endotracheal resuscitation using a bag system is still commonly used and may give different results from a finger occlusion technique. Indeed, a slow rise inflation has been shown to be more effective than a square wave.[8]

We have therefore studied endotracheal resuscitation of asphyxiated neonates using a bag for inflation and a system that limits neither pressure nor volume.

Subjects and methods

Babies who required endotracheal resuscitation were intubated with a shouldered Portex endotracheal tube. The largest tube possible (size 2·5 or 3·0) was used for each individual baby to avoid problems of leak around the endotracheal tube. The lungs of intubated babies were inflated using a 0·75 l anaesthetic rebreathing bag (Medishield) connected with a Fleisch 0 pneumotachograph to the proximal end of the endotracheal tube (fig 1). Tidal flow was measured from the pneumotachograph with a Furness Controls differential pressure transducer (FCO40, range±20 mm Hg). Inflation pressure was measured from a Furness Controls transducer (FCO40, range±1000 mm Hg) attached to the connecting piece between the endotracheal tube and the pneumotachograph. The 63% response time of the pneumotachograph (calculated by bursting balloons connected to the system) was 8 ms, giving a 3 dB/octave loss at 20 Hz. The response time of the pressure transducer was similar (10 ms) giving a 3 dB/octave loss at 16 Hz.

Pressure and flow signals were recorded on to tape during resuscitation, and flow subsequently digitally integrated to obtain volume.

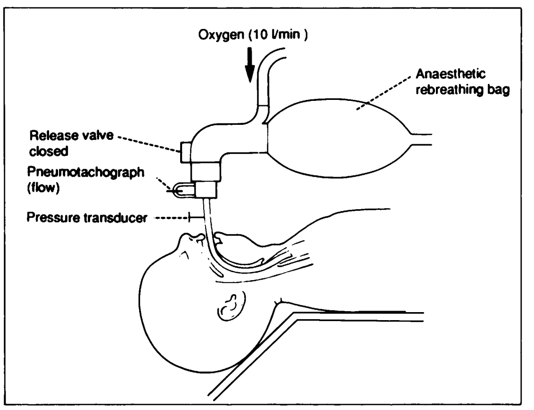

Figure 1 Diagram of resuscitation system.

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The response of the equipment was linear to within 5% over a range of pressures of 5 to 50 cm H_2O and volumes of 2 to 50 ml. After each resuscitation the calibration was checked with a water manometer to measure 20 cm H_2O pressure and with a syringe to measure 10 ml volume.

During resuscitation the blow off valve on the rebreathing bag was kept closed. The end of the bag was open, however, and was controlled by the fingers of the resuscitator (CJU in all cases). The bag was supplied with a flow of oxygen of 10 l/min from a cylinder with no blow off valve in line. Chest movement was observed closely and the bag gently squeezed until inflation was observed (fig 1). A rate of inflation of 40 breaths/minute was our aim, and the inflation time was prolonged as much as possible with a bag volume of 0·75 l.

The whole system was portable but some warning was necessary; only high risk deliveries were attended, therefore. If the delivery was elective, then the procedure was discussed with the parent(s) beforehand.

Eighty two high risk deliveries were attended between February 1988 and June 1989. Thirty two infants required intubation for resuscitation, but only 30 were successfully studied as two twins were born in such rapid succession that they had to be resuscitated conventionally. Babies were only given endotracheal resuscitation if they were apnoeic with an Apgar score of 4 or less after one minute, or had failed to respond to intermittent positive pressure ventilation (IPPV) by mask.[9] Preterm infants were not intubated electively.

The modes of delivery are shown in table 1. Fifteen mothers were in labour and 15 were not. Sixteen boys and 14 girls were resuscitated, with a median birth weight of 1760 g (range 580–3980) and gestation of 33 weeks (range 26–42). Twenty two of the infants were preterm. Eighteen of the 30 made some respiratory effort, usually weak, before becoming apnoeic and eight infants were given IPPV by mask before intubation. Four infants required suction for meconium below the cords before the initiation of endotracheal IPPV. The median 1 minute Apgar score was 3 (range 1–8) and all resuscitations were successful, with a median 5 minute Apgar score of 8 (range 5–9). None of the infants required external cardiac massage and only one needed treatment with intravenous dextrose and sodium bicarbonate while on the resuscitaire.

After resuscitation, pressure and volume signals were played from the tape on to a chart recorder (Devices) with a paper speed of 10 mm/s. Values of pressure and volume were calculated manually from the beginning of the trace and compared with a period just before the onset of regular respiration, usually at around 1 minute. The mean value from 10 inflations was obtained from each part of the trace but only those where the pressure and volume peaks coincided were used for analysis, necessitating the use of smaller numbers on four occasions. Paired observations were compared with the Wilcoxon ranked sum test, and unpaired data with the Mann-Whitney U test. Variables were analysed for the effect of gestation and birth weight using regression analysis. Outcome was analysed with respect to presence or absence of functional residual capacity formation using Fisher's exact test. Numbers of effective initial inflations were compared with historical data with the χ^2 test. Approval for the study was given by the Nottingham ethics committee.

Results

Full results are shown in table 2. The median rate of inflation was 48 breaths/minute during the early part of resuscitation, with a median inspiratory time of 0·51 s. The maximum pressure of any single inflation ranged up to 73 cm H_2O. The median mean pressure during the early part of resuscitation was 40 cm H_2O, and this dropped to 29 cm H_2O during later resuscitation ($p<0·0001$). The inflation pressure may have dropped as the baby responded simply as a result of relief on the part of the resuscitator. Volumes delivered increased slightly as the pressure dropped, however, from a median of 8·6 to 9·7 ml/kg; this was not significant. Volume was divided by pressure to give a measure of the efficiency of resuscitation; this was not true compliance as the volume trace did not plateau. Median volume/pressure virtually doubled during resuscitation, from 0·18 to 0·35 ml/kg/cm H_2O ($p<0·0001$). Median inflation volume for the first inflation was 8·7 ml/kg (range 0–23·4), which was similar to the median mean over the first 10 inflations. This was significantly better than historical data from Boon *et al* who showed a median inflation volume for the first breath of 4·6 ml/kg (range 0–18·4) using a blow off pressure of 30 cm H_2O and an occlusion technique ($p<0·0001$).[6]

The number of the first three inflations that yielded an arbitrary volume of 4·4 ml/kg was also calculated by the method of Hoskyns *et al*.[10] This was chosen to be roughly two anatomical dead spaces. Overall, 58 of 90 inflations (64%) delivered at least 4·4 ml/kg. Among the preterm infants the proportions were similar, with 43 of 66 inflations (65%) reaching 4·4 ml/kg. This compares favourably with historical data from Hoskyns *et al*, who also used a pressure blow off valve set at 30 cm H_2O and an occlusion technique.[10] In their study of 21 preterm infants only 18 out of 63 initial inflations (29%) reached 4·4 ml/kg, a significantly smaller proportion than in the present study ($p<0·001$).

Table 1 Mode of delivery

	No of infants
Emergency caesarean section	19
Breech delivery	5
Elective caesarean section	3
Normal vaginal delivery	2
Forceps delivery	1
Total	30

Table 2 Pressures and volumes during early and late resuscitation

	Median	*Range*
Maximum pressure (cm H_2O)	50	33–73
Early mean pressure (cm H_2O)	40	28–60
Early volume (ml/kg)	8·6	1·1–22·5
Early volume/pressure (ml/kg/cm H_2O)	0·18	0·03–0·42
Late mean pressure (cm H_2O)	29	18–42
Late volume (ml/kg)	9·7	2·1–20·4
Late volume/pressure (ml/kg/cm H_2O)	0·35	0·06–0·81

The results of the pressure/volume relationships were analysed by simple regression analysis to see if gestational age, birth weight, or Apgar scores had an effect. No trends were apparent; pressures required seemed to be randomly distributed among the babies.

Preterm infants required neither higher nor lower pressures, and whether or not the mother was in labour made no significant difference to any of the variables listed in table 2.

Figure 2 shows the initial resuscitation of a preterm infant of 32 weeks' gestation. More volume goes in than out over the first four inflations giving a stepwise formation of the functional residual capacity. She did not breathe before intubation. If she had, then clearly the formation of the functional residual capacity could have been missed. In 14 infants the functional residual capacity was formed in this stepwise fashion with artificial ventilation, but in 11 there was no evidence of functional residual capacity formation. A different pattern is seen in fig 3, which shows the initial resuscitation of an infant of 30 weeks' gestation. He did not breathe before laryngoscopy but took two gasps immediately after intubation. Part of his functional residual capacity was formed with these spontaneous breaths, but little added with the subsequent artificial ventilation. Five infants formed their functional residual capacities in this way, with spontaneous but not artificial breaths. There were no significant differences in the pressure/volume relationships between those babies who were seen to form functional residual capacities and those babies who were not.

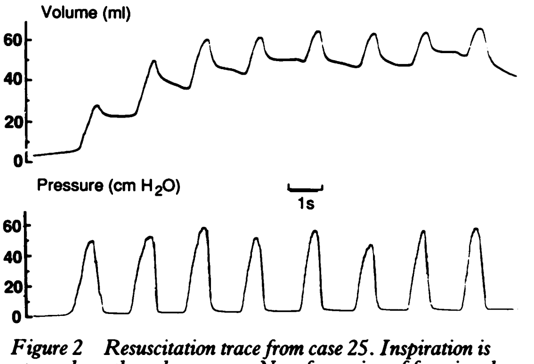

Figure 2 Resuscitation trace from case 25. Inspiration is upwards on the volume trace. Note formation of functional residual capacity over the first four inflations.

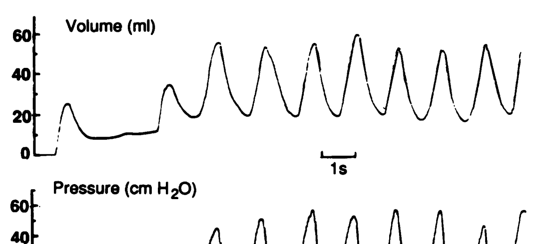

Figure 3 Resuscitation trace from case 22. Inspiration is upwards. Note two spontaneous gasps before onset of IPPV with part of functional residual capacity being formed with the spontaneous, but not artificial ventilation.

All but five infants were admitted to the neonatal intensive care unit, mainly because of prematurity or respiratory disease. Only one baby was admitted simply because of the birth asphyxia, and no infant developed more than mild postasphyxial encephalopathy. Despite the high initial pressures there were no pneumothoraces and all but five infants had a chest radiograph taken. Seven infants were ventilated for hyaline membrane disease of whom four died. One baby of 26 weeks' gestation was ventilated electively after resuscitation but found to have no respiratory disease and he was successfully extubated at 24 hours. There were three other deaths in infants who did not have hyaline membrane disease and none of these was related to the asphyxia. Two of these infants had congenital abnormalities (one had Edwards' syndrome and one had a diaphragmatic hernia) and the other died of overwhelming sepsis at the age of 10 days.

There was no correlation between the use of higher initial pressures or more effective volume/pressure relationships and later outcome, which was not surprising as we were using a system with no pressure limit and as the babies with stiffer lungs needed higher pressures to achieve visible chest movements.

There was, however, an apparent effect of functional residual capacity formation on outcome, particularly with respect to hyaline membrane disease, as none of the four babies who died with hyaline membrane disease had shown evidence of functional residual capacity formation. We therefore analysed the results of the 22 preterm infants separately (table 3). There was a significant association between hyaline membrane disease requiring ventilation and the absence of functional residual capacity formation, and conversely between its presence and mild (requiring headbox oxygen only) or no disease ($p=0{\cdot}02$).

Discussion

The results of this study have shown that a median pressure of 40 cm H_2O is required to inflate the chests of intubated, asphyxiated neonates during the first 10 inflations. This is not surprising as during spontaneous first breaths babies generate negative intrathoracic pressure of 40 to 100 cm H_2O.[11] The required pressure falls as resuscitation continues, and in our study the median pressure dropped to 29 cm H_2O just before regular respiration started. This confirms previous work with a system in which volume was limited.[4] The lungs at

Table 3 Relationship between absence of formation of functional residual capacity and later severe hyaline membrane disease in 22 preterm infants

	Formation of functional residual capacity	*No functional residual capacity seen*	*p Value**
Mild or no hyaline membrane disease	10	3	0·02
Severe hyaline membrane disease (requiring ventilation)	2	7	

*Fisher's exact test (two tailed).

birth are filled with fluid resulting in a low initial compliance, but as this clears the compliance increases and lower pressure may inflate the chest.[4 8]

We have also shown that considerable improvements in ventilation can be achieved over the first one to three breaths using a rebreathing bag with no pressure limit, compared with historical data using a finger occlusion technique and a pressure limit of 30 cm H_2O.[6 10] Clearly there are drawbacks to using historical data for comparison, but the methods for measuring pressures and volumes at resuscitation were similar in all the studies. The more effective initial ventilation we have observed may not necessarily be the result of the higher pressures used. Both the inflation time and waveform of the inflation pressure are known to be important factors.[8] The inflation time in our study was actually shorter, however, (median 0·51 s) than the 1 second used by both Boon *et al* and Hoskyns *et al*.[6 10] The waveform produced by the rebreathing bag may have been more effective than a square wave, though whether this is important with a shorter inflation time is debatable. The improvement in slow rise inflation shown by Vyas *et al* was over 3–5 s.[8] We therefore believe that it is the increased pressures that we used that resulted in the improved ventilation. Improved early ventilation may also be achieved by the use of a longer inflation time but clearly this may result in a lower frequency of inflation and lower minute ventilation, compared with the shorter inflation times used in the present study.[8]

The use of an anaesthetic rebreathing bag in this study permitted us to observe chest movement during a slow rise inflation and thereby avoid excessive pressure. We would have liked to have used a longer inflation time but this proved difficult with the volume of the bag. The arguments for and against the use of rebreathing bags have been discussed by Kanter.[12] He believed that they had advantages in experienced hands and especially when ventilating through an endotracheal tube. The technique is not easy to learn, however, and we would feel that it is inappropriate for rebreathing bags to be used routinely by inexperienced junior medical staff or midwives.

Self inflating resuscitators are also commonly used but these also have limitations. They have been shown in experienced hands to deliver inflation times of only up to half a second[7]; in inexperienced hands we have noted considerably shorter inflation times. They tend to have unreliable blow off valves and may not deliver the required concentration of oxygen.[13] They are also clumsy to use, especially when connected to an unfixed endotracheal tube. Clearly, improvements to the available self inflating resuscitation bags are necessary before their widespread use can be recommended.[14]

We continue to use the finger occulsion technique routinely for both endotracheal [5] and face mask resuscitation.[10] This allows the use of longer inflation times, can be done with one hand, is easy to learn, and is generally effective.

It is difficult to extrapolate from the group of high risk infants resuscitated in this study to the general population of intubated neonates. Careful consideration should be given, however, to increasing the blow off pressure during initial resuscitation to at least 40 cm H_2O. Indeed, half our infants required mean initial pressures greater than this before chest inflation occurred. If chest movement is poor and the baby is slow to respond to resuscitation, then an increase in inflation pressure may well be helpful. Nevertheless there is a worry that in inexperienced hands such a high pressure may be used later in resuscitation and be harmful. Indeed, evidence from 30 resuscitations is not sufficient to ensure the safety of using higher pressures, even during initial resuscitation; further work is necessary to draw up new guidelines for endotracheal resuscitation.

Previous studies have not been able to correlate outcome with any of the measurements made during resuscitation. We have shown a strong correlation between absence of functional residual capacity formation in preterm infants and later hyaline membrane disease requiring ventilation. This association was confounded by the fact that some babies breathed before intubation and therefore functional residual capacity formation may have been missed. This makes the strong association seen here even more impressive. The ability of such a system to predict severe hyaline membrane disease would, however, be limited by any cries that the baby made before intubation. It is interesting to postulate, though, that the lack of functional residual capacity formation is the result of surfactant deficiency and that this can be detected within the first few breaths. It could also be assumed that atelectasis occurs between each inflation and makes resuscitation less efficient. It is therefore possible that a resuscitation device that delivered positive end expiratory pressure would be of benefit to preterm infants. Such a device would certainly warrant serious investigation.

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